CrossMark

From the New England Society for Vascular Surgery

Follow-up compliance after endovascular abdominal aortic aneurysm repair in Medicare beneficiaries

Andres Schanzer, MD,[a] Louis M. Messina, MD,[a] Kaushik Ghosh, PhD,[b] Jessica P. Simons, MD, MPH,[a] William P. Robinson III, MD,[a] Francesco A. Aiello, MD,[a] Robert J. Goldberg, PhD,[a] and **Allison B. Rosen, MD, MPH, ScD,[a,b]** *Worcester and Cambridge, Mass*

Objective: **Lifelong imaging follow-up is essential to the safe and appropriate management of patients who undergo endovascular abdominal aortic aneurysm repair (EVAR). We sought to evaluate the rate of compliance with imaging follow-up after EVAR and to identify factors associated with being lost to imaging follow-up.**

Methods: **We identified a 20% sample of continuously enrolled Medicare beneficiaries who underwent EVAR between 2001 and 2008. Using data through 2010 from Medicare Inpatient, Outpatient, and Carrier files, we identified all abdominal imaging studies that may have been performed for EVAR follow-up. Patients were considered lost to annual imaging follow-up if they did not undergo any abdominal imaging study within their last 2 years of follow-up. Multivariable models were constructed to identify independent factors associated with being lost to annual imaging follow-up.**

Results: **Among 19,962 patients who underwent EVAR, the incidence of loss to annual imaging follow-up at 5 years after EVAR was 50%. Primary factors associated with being lost to annual imaging follow-up were advanced age (age 65-69 years, reference; age 75-79 years: hazard ratio [HR], 1.23; 95% confidence interval [CI], 1.15-1.32; age 80-85 years: HR, 1.45; 95% CI, 1.35-1.55; age >85 years: HR, 2.03; 95% CI, 1.88-2.20) and presentation with an urgent/emergent intact aneurysm (HR, 1.27; 95% CI, 1.20-1.35) or ruptured aneurysm (HR, 1.84; 95% CI, 1.63-2.08). Additional independent factors included several previously diagnosed chronic diseases and South and West regions of the United States.**

Conclusions: **Annual imaging follow-up compliance after EVAR in the United States is significantly below recommended levels. Quality improvement efforts to encourage improved compliance with imaging follow-up, especially in older patients with multiple comorbidities and in those who underwent EVAR urgently or for rupture, are necessary. (J Vasc Surg 2015;61:16-22.)**

The management of abdominal aortic aneurysms (AAAs) has traditionally depended on open surgical repair.[1,2] Recent advances in catheter-based, endovascular techniques have led to a substantial increase in the proportion of AAAs managed with endovascular aortic aneurysm repair (EVAR). In 2006, 21,725 EVAR procedures were performed in the United States, exceeding for the first time the number of open surgical AAA repairs.[3] Currently, more than 80% of AAA repairs in the United States are performed by EVAR.[4]

Multiple guidelines recommend annual lifelong imaging follow-up after EVAR to identify and to correct complications such as endoleaks or residual aortic sac enlargement and thereby prevent death due to aneurysm rupture after EVAR.[5,6] Recent evidence from several longitudinal investigations indicates that rates of late aneurysm sac enlargement are unexpectedly high, increasing the risk of death due to rupture after EVAR.[7-9] In a study of 27 patients presenting with AAA rupture after EVAR during the period 2002-2009, approximately three quarters had been lost to follow-up before rupture.[10] Accordingly, annual lifelong imaging follow-up with computed tomography (CT), magnetic resonance imaging (MRI), or duplex ultrasound is essential to the safe and appropriate management of patients undergoing EVAR.

Despite the critical importance of annual lifelong imaging follow-up after EVAR, little is known about compliance with this requirement.[11,12] We hypothesized that among Medicare beneficiaries treated with EVAR, a significant proportion of patients are lost to annual imaging follow-up and that there are several patient characteristics associated with loss to annual imaging follow-up. To test this hypothesis, we examined Medicare claims data to identify a group of patients who underwent EVAR between 2001 and 2008 and estimated the proportion lost

From the University of Massachusetts Medical School, Worcester[a]; and the National Bureau of Economic Research, Cambridge.[b]

This research was supported by P01AG031098 from the National Institute on Aging and UL1TR000161 from the National Center for Research Resources.

Author conflict of interest: A.S. receives a consulting fee from Cook Medical and Bolton Medical.

Presented at the Forty-first Annual Meeting of the New England Society for Vascular Surgery, Boston, Mass, September 11-14, 2014.

Additional material for this article may be found online at www.jvascsurg.org.

Reprint requests: Andres Schanzer, MD, Division of Vascular and Endovascular Surgery, UMass Memorial Medical Center, 55 Lake Ave North, Worcester, MA 01655 (e-mail: andres.schanzer@umassmemorial.org).

The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

http://dx.doi.org/10.1016/j.jvs.2014.06.006

to imaging follow-up for an extended duration of follow-up. A secondary objective of this observational study was to examine patient-related factors associated with loss to annual imaging follow-up for which increased efforts directed at follow-up compliance are warranted.

METHODS

Data sources. We conducted a retrospective cohort study using 2001-2010 enrollment and claims data for a 20% national sample of Medicare beneficiaries selected by the Centers for Medicare and Medicaid Services in constructing their standard Part B (physician services) claims files (needed to identify imaging follow-up in our study). Data on EVAR procedures were obtained from the U.S. Medicare Provider Analysis and Review files, which contain hospital discharge abstracts for the acute care hospitalizations of all Medicare beneficiaries with Part A coverage. The data include admission and discharge dates, International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes and dates, admission type (categorized as elective, urgent, and emergent), and discharge disposition. Imaging data were obtained from Hospital Inpatient, Outpatient, and Carrier files. These files were linked to Medicare Denominator files, which include information on beneficiaries' date of birth, sex, race/ethnicity (categorized as black, white, or other), enrollment status, region of residence (Midwest, Northeast, South, or West), and vital status (including date of death). Follow-up imaging was evaluated for all patients through December 31, 2010.

Cohort identification. The study cohort was defined by identifying Medicare fee-for-service beneficiaries 65 years or older who underwent EVAR between January 1, 2001, and December 31, 2008. Eligibility was limited to those continuously enrolled in Medicare Parts A and B (as identified through Denominator files) from the time of their EVAR until the end of the study period or death. Patients were excluded if they resided outside the United States or were enrolled in a Medicare health maintenance organization during the study window.

Patients who underwent EVAR were identified on the basis of an ICD-9 diagnosis code for AAA with (441.3) or without rupture (441.4) as well as an ICD-9 procedure code for EVAR (39.71). To limit the cohort to patients who underwent EVAR for infrarenal AAA and to minimize misclassification errors, patients were excluded for diagnosis and procedure codes related to the thoracic aorta or visceral segment aorta (Supplementary Table I, online only).

Identification of imaging studies performed during EVAR follow-up. To identify any abdominal imaging study that might have been performed for EVAR follow-up, the Inpatient, Outpatient, and Carrier files were queried for billing codes consistent with an abdominal or pelvic CT, MRI, or duplex ultrasound study (Supplementary Table II, online only). The billing codes included were intentionally broad to mitigate the risk of missing potentially relevant imaging studies.

Patient covariates. Patient sociodemographic characteristics examined included age, sex, race, and residential location by region of the United States. Median household income by the beneficiary's zip code of residence was obtained from U.S. Census files.[13] The indication for EVAR was classified as elective intact aneurysm, urgent or emergent intact aneurysm, or ruptured aneurysm. A partial list of relevant comorbidities used in the Klabunde adaptation of the Charlson Comorbidity Index was identified by a 1-year look-back from the index EVAR admission date.[14,15] Comorbidities included ischemic heart disease, congestive heart failure, cerebrovascular disease, chronic obstructive pulmonary disease, chronic renal dysfunction, diabetes, cancer, hypertension, and hyperlipidemia.

Outcome measures. The primary study end point was loss to annual imaging follow-up. Patients were considered lost to annual imaging follow-up in the following two situations:

1. If the patient was alive at the end of the follow-up period (December 31, 2010) and did not have any claim submitted for an imaging study (CT, MRI, or duplex ultrasound) within the 2 years before the end of the follow-up period.

Table I. Baseline characteristics of Medicare beneficiaries who underwent endovascular aneurysm repair (EVAR) between 2001 and 2008 (N = 19,962)

Variable	*No. (%)*
Men	16,368 (82)
Age, years	
65-69	3393 (17)
70-74	4791 (24)
75-79	5390 (27)
80-84	4192 (21)
≥85	2196 (11)
Race	
White	18,764 (94)
Black	599 (3)
Other	599 (3)
Mean family income quartile	
Lowest quartile (0%-25%)	4969 (24.89)
Low medium quartile (26%-50%)	4988 (24.99)
High medium quartile (51%-75%)	4954 (24.82)
Highest quartile (76%-100%)	5051 (25.30)
Region of the United States	
Northeast	3793 (19)
Midwest	5390 (27)
South	8384 (42)
West	2395 (12)
Comorbidities	
Ischemic heart disease	9182 (46)
Congestive heart failure	2595 (13)
Cerebrovascular disease	2195 (11)
Chronic obstructive pulmonary disease	6387 (32)
Chronic renal dysfunction	1596 (8)
Diabetes	3992 (20)
Cancer	2994 (15)
Hypertension	14,173 (71)
Hyperlipidemia	10,779 (54)
Presentation	
Elective intact aneurysm	16,856 (84)
Urgent or emergent intact aneurysm	2626 (13)
Ruptured aneurysm	480 (2)

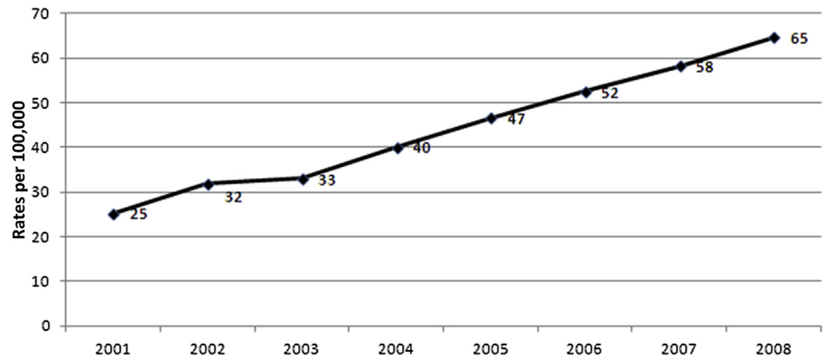


Fig 1. The number of hospitalizations for endovascular aneurysm repair (EVAR) procedures per 100,000 Medicare beneficiaries between 2001 and 2008.

2. If the patient died during the follow-up period and did not have any claim submitted for an imaging study (CT, MRI, or duplex ultrasound) within the 2 years before the date of death.

A 2-year span was used to provide an adequate time window to ensure that loss to annual imaging follow-up was not overestimated.

The secondary end point evaluated was the presence of a prolonged imaging gap after EVAR. Patients were considered to have a prolonged imaging gap if they did not undergo at least one imaging study during each 2-year interval that they were alive after EVAR.

Statistical methods. Annual incidence of EVAR procedures performed between 2001 and 2008 is reported as procedure rates per 100,000 Medicare beneficiaries. After a patient was determined to be lost to annual imaging follow-up by the methodology presented before, the time-to-event occurrence of loss to annual imaging follow-up was analyzed by the Kaplan-Meier method, with the time duration assigned being 2 years from the last obtained imaging study. Between-group differences in stratified analyses were compared by the log-rank test. For all survival analyses, observations were censored at the time of death, and Kaplan-Meier curves were generated without the use of a smoothing function. To identify independent predictors of loss to annual imaging follow-up, all potential sociodemographic risk factors in Table I were introduced into a multivariable Cox proportional hazards model using backward stepwise selection.

The proportion of patients with a prolonged imaging gap for each 2-year window after EVAR (0-1.9 years, 2-3.9 years, 4-5.9 years, and 6-8 years) was calculated at the patient level by the following equation:

$$100\% - \left(\frac{\text{No. of patients with} \geq 1 \text{ imaging study during 2-year interval}}{\text{No. of patients alive during 2-year interval}} * 100\right)$$

All analyses were performed with SAS 9.2 (SAS Institute, Cary, NC); two-tailed *P* values $< .05$ were considered statistically significant. This study was approved by the Institutional Review Board at the University of Massachusetts Medical School and patient consent was waived for this study.

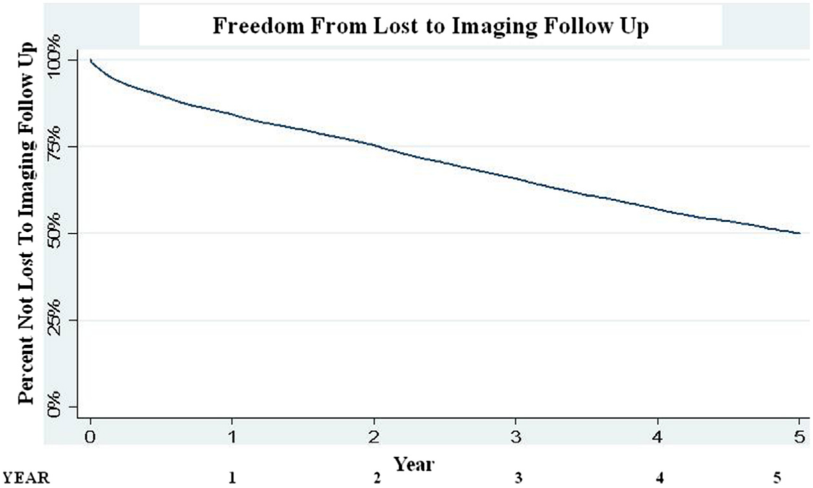
RESULTS

The study population consisted of 19,962 Medicare beneficiaries aged 65 years and older who underwent EVAR between 2001 and 2008. The patients were primarily men (82%) and white (94%), with an average age of 76.3 years and a median household income of $49,746, representing all regions of the United States (Table I). Patients who underwent EVAR had a high burden of cardiovascular risk factors including ischemic heart disease (46%), diabetes (20%), hypertension (71%), and hyperlipidemia (54%). Eighty-four percent of EVARs were performed electively, 13% urgently or emergently for intact aneurysm, and 2% emergently for ruptured aneurysm.

During the study period, the absolute number of hospitalizations for EVAR increased markedly (from 1400 in 2001 to 3529 in 2008), representing a more than 2.5-fold increase in the annual incidence of EVAR procedures (from 25 EVARs per 100,000 Medicare beneficiaries in 2001 to 65 EVARs per 100,000 Medicare beneficiaries in 2008; *P* value for trend $< .001$) (Fig 1).

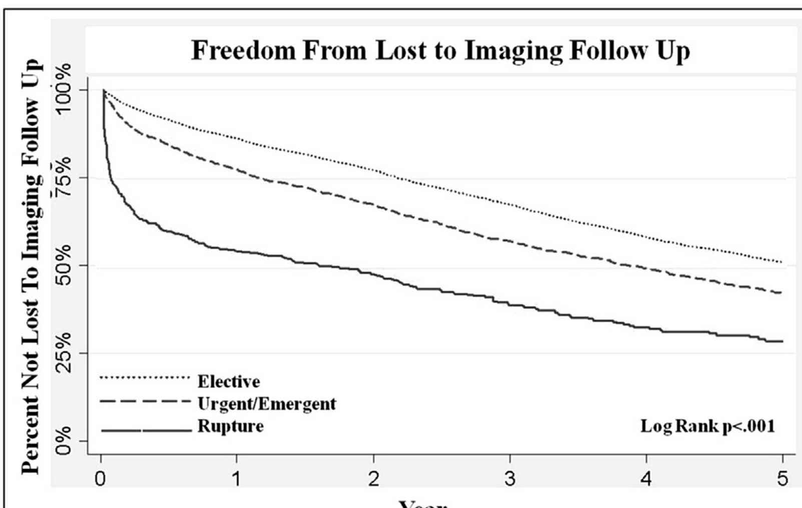
Loss to annual imaging follow-up. The mean duration of follow-up was 5 ± 2.6 years. The proportion of patients lost to annual imaging follow-up on Kaplan-Meier analysis at 1, 3, and 5 years after EVAR was 22% (standard error, .0003), 38% (standard error, .004), and 50% (standard error, .004), respectively. Loss to annual imaging follow-up appeared to increase steadily throughout the study period, with no evidence of a plateau or slow-down in the slope of the Kaplan-Meier curve (Fig 2).

On univariable analysis, the proportion of patients lost to annual imaging follow-up was significantly associated with the relative urgency of the EVAR procedure (Fig 3). Patients treated with EVAR for ruptured AAA were significantly more likely to be lost to annual imaging follow-up than were patients treated with EVAR for intact AAA ($P <$ .001). This effect was also seen when patients treated for intact aneurysms were further stratified on the basis of urgent/emergent status vs elective status. Patients undergoing



YEAR	1	2	3	4	5
NUMBER AT RISK	16,243	13,040	9,161	6,105	3,882
KM ESTIMATE	84.2	75.4	65.8	57.0	50.1
STANDARD ERROR	0.003	0.003	0.004	0.004	0.004

Fig 2. Kaplan-Meier (*KM*) analysis of all patients who underwent endovascular aneurysm repair (EVAR) between 2001 and 2008 demonstrating the proportion of patients not lost to imaging follow-up.



NUMBER AT RISK					
YEAR	1	2	3	4	5
ELECTIVE	14,041	11,324	8,000	5,340	3,398
URGENT_EMERGENT	1956	1520	1040	688	433
RUPTURE	255	195	121	78	51
KM ESTIMATE					
YEAR	1	2	3	4	5
ELECTIVE	0.86	0.77	0.68	0.59	0.52
URGENT_EMERGENT	0.77	0.68	0.58	0.50	0.43
RUPTURE	0.55	0.48	0.40	0.33	0.30
STANDARD ERROR					
YEAR	1	2	3	4	5
ELECTIVE	0.003	0.003	0.004	0.004	0.005
URGENT_EMERGENT	0.008	0.009	0.010	0.011	0.012
RUPTURE	0.023	0.023	0.024	0.025	0.025

Fig 3. Kaplan-Meier (*KM*) analysis of all patients who underwent endovascular aneurysm repair (EVAR) between 2001 and 2008 demonstrating the proportion of patients not lost to imaging follow-up, stratified by presentation at the time of repair—elective, urgent/emergent, ruptured.

intact AAA repair urgently or emergently had higher rates of being lost to annual imaging follow-up than did patients undergoing elective AAA repair ($P < .001$). This observed increase in being lost to annual imaging follow-up occurred predominantly during the first 2 years of follow-up. The subsequent rate of being lost to imaging follow-up during years 3, 4, and 5 occurred at a similar rate across all groups (Fig 3).

Table II. Independent determinants of being lost to imaging follow-up after endovascular aneurysm repair (EVAR)

Variable	*HR*	*95% CI*
Age, years		
65-69	Reference	Reference
70-74	1.04	0.97-1.12
75-79	1.23	1.15-1.32
80-85	1.45	1.35-1.55
>85	2.03	1.88-2.20
U.S. region		
East	Reference	Reference
Midwest	1.05	0.98-1.11
South	1.1	1.03-1.17
West	1.16	1.07-1.25
Comorbidities		
Congestive heart failure	1.52	1.43-1.61
Cerebrovascular disease	1.07	1.01-1.15
Chronic obstructive pulmonary disease	1.29	1.23-1.35
Chronic renal insufficiency	1.37	1.27-1.49
Diabetes	1.07	1.02-1.13
Cancer	1.12	1.06-1.19
Presentation		
Elective nonruptured	Reference	Reference
Urgent/emergent nonruptured	1.27	1.20-1.35
Ruptured	1.84	1.63-2.08

CI, Confidence interval; *HR,* hazard ratio.

On multivariable analysis, the factors associated with loss to annual imaging follow-up that had the largest hazard ratios were advanced age and aneurysm rupture on presentation (Table II). Additional independent predictors of loss to annual imaging follow-up included previous histories of congestive heart failure, chronic renal insufficiency, chronic obstructive pulmonary disease, cancer, cerebrovascular disease, and diabetes and South and West regions of the United States.

Prolonged imaging gap. Figure 4 demonstrates the proportion of patients who received ≥1 imaging study (CT, MRI, or duplex ultrasound) during each 2-year interval after EVAR. Of the 18,914 patients alive 2 years after EVAR, 94.8% received ≥1 imaging study after EVAR. For the 13,307 patients alive 4 years after EVAR, 69.6% received ≥1 imaging study between years 2 and 4 after EVAR. For the 7666 patients alive 6 years after EVAR, 49.4% received ≥1 imaging study between years 4 and 6 after EVAR. For the 3239 patients alive 8 years after EVAR, 36.6% received ≥1 imaging study between years 6 and 8 after EVAR.

DISCUSSION

This study demonstrates that in a large population of Medicare beneficiaries who underwent EVAR between 2001 and 2008, 50% of patients were lost to annual imaging follow-up by 5 years after EVAR. For the subset of patients with 8 years of follow-up data after EVAR, substantive declines in imaging follow-up continued, with only 37% undergoing an imaging study between years 6 and 8. These rates are surprisingly low, given the clear evidence supporting the importance of annual imaging follow-up for identifying correctable problems after EVAR that can lead to aneurysm sac enlargement, rupture, and death.[5-10]

It is possible that a proportion of the patients categorized as "lost to annual imaging follow-up" were not truly "lost" but may have stopped receiving follow-up by choice, or they may have been told by their physician that they no longer needed further follow-up. Either way, compliance with recommended lifelong imaging follow-up after EVAR was poor. The exact motivation leading to this poor compliance is an interesting and important question that, unfortunately, is beyond the scope of this study and cannot be addressed with this data set.

Despite the critical importance of annual imaging follow-up after EVAR, few studies have examined compliance with this guideline-recommended management, and U.S. data are limited to single-institution studies.[5,6] Jones et al analyzed follow-up compliance in 302 patients who underwent EVAR at a single institution (1999-2005).[11] During an average follow-up of 30 months, 33% of patients had incomplete follow-up (defined as missing ≥2 consecutive imaging studies). In another single-center review with a more heterogeneous population (patients underwent EVAR, endovascular thoracic aneurysm repair, or medical management for type B aortic dissection), imaging follow-up compliance was assessed in 204 patients.[12] At an average follow-up of 28 months, 56% of patients were lost to imaging follow-up (defined as >1 year since last imaging).

To our knowledge, our study provides the first population-based estimates of post-EVAR annual imaging follow-up rates for the United States. In Europe, an attempt has been made to better understand factors associated with loss to imaging follow-up.[16] The European Collaborating Group on Stent-Graft Techniques for Abdominal Aortic Aneurysm Repair recommends lifelong annual imaging follow-up after EVAR. With use of data from 4433 patients enrolled in this registry during the period 1996-2004, 65% failed to comply with the recommended follow-up regimen. On multivariable analysis, compliance was associated with the number of comorbidities and cardiovascular risk factors present. Patients who were hypertensive, actively smoked, and deemed medically too high risk for open repair were more likely to comply with imaging follow-up.

In contrast to the European findings, it appears that Medicare beneficiaries are more likely to be lost to annual imaging follow-up if they have multiple comorbidities previously diagnosed. Congestive heart failure, cerebrovascular disease, chronic obstructive pulmonary disease, chronic renal insufficiency, diabetes, and cancer were associated with a significantly increased hazard of loss to annual imaging follow-up. One possible explanation for this finding may be that in patients with a number of active long-term medical issues, the patient and treating physicians may lose focus on surveillance of an AAA after

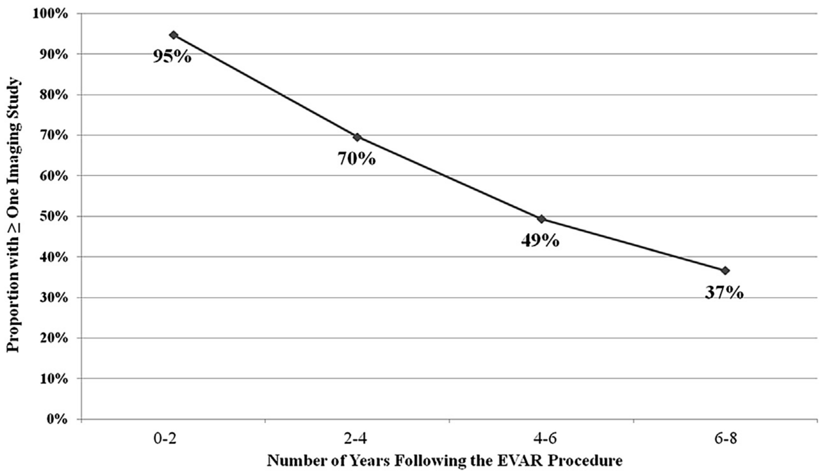


Fig 4. Prolonged imaging gap. Proportion of patients who received at least one imaging study (computed tomography [CT], magnetic resonance imaging [MRI], or duplex ultrasound) during each 2-year interval that they were alive after endovascular aneurysm repair (*EVAR*).

EVAR because of the demands of caring for their high burden of competing medical risks.

Older individuals were also more likely to be lost to annual imaging follow-up. Not surprisingly, each 5-year increment of advanced age was associated with a significant increase in being lost to imaging follow-up. Because the duration of remaining life expectancy decreases with advancing age, the perceived benefit of regular surveillance after EVAR may decrease as well. In a patient older than 85 years (hazards ratio for loss to imaging follow-up, 2.03), the value of performing a reintervention, even if a problem is identified after EVAR, becomes less clear.

Surprisingly, patients who underwent EVAR in the urgent/emergent setting and those who presented with a ruptured AAA were significantly more likely to be lost to annual imaging follow-up. The reasons for this are likely to be multifactorial. First, patients undergoing elective EVAR have been counseled by the treating physician, often on multiple visits, and may have a better underlying understanding of their disease and the critical importance of lifelong imaging follow-up. Second, patients being treated in the urgent/emergent setting are often treated outside of their established health care network and are more likely to be lost to follow-up. These findings point to an important opportunity for national quality improvement efforts to enhance care coordination across providers of care and to reward appropriate imaging follow-up among patients at high risk for loss to follow-up. Novel ideas to improve imaging follow-up compliance, such as physician-patient contracts, improved preoperative education materials, and financial incentives directed at both patients and physicians, need to be developed and tested.

There are several strengths and limitations inherent to this study design. First, our cohort was limited to elderly Medicare beneficiaries, and we cannot comment on post-EVAR follow-up imaging rates among individuals younger than 65 years. Second, we restricted analyses to Medicare fee-for-service enrollees, as Medicare managed care enrollees frequently have incomplete claims and therefore incomplete capture of follow-up imaging data. If follow-up imaging compliance is higher among Medicare Advantage enrollees, our imaging compliance estimates may be low. Offsetting this potential bias, we defined loss to annual imaging follow-up liberally (2 years without an imaging study) instead of using a more stringent definition (1 year without an imaging study). This was deliberate to avoid overestimating the rate of loss to annual imaging follow-up. As a result, the true rate of loss to annual imaging follow-up is likely to be significantly higher than reported here. Finally, it is possible that a proportion of the imaging studies identified during the follow-up period were indicated for reasons other than post-EVAR surveillance. Whereas the AAA may have been imaged, we were unable to know if a physician with expertise in evaluating an EVAR repair reviewed the imaging study.

An important question that arises on the basis of these data is, How many patients who were lost to imaging follow-up progressed to AAA rupture after EVAR compared with those who were not lost to imaging follow-up? In many ways, this is the key clinical question that begins to quantify the importance of annual lifelong imaging follow-up after EVAR. Unfortunately, this is a difficult question to answer with administrative claims data as the majority of patients who experience AAA rupture do not make it to the hospital. As a result, these events are not captured in administrative data such as the Medicare files used in this study. Furthermore, we are unable to comment on the proportion of follow-up imaging studies that demonstrated abnormalities related to the EVAR procedure as the data set contains no results from the imaging study. We are limited to being able to report only whether or not they had an imaging study on the basis of the claims submitted.

CONCLUSIONS

These findings suggest that compliance with imaging follow-up recommendations after EVAR in the United States is well below the recommended rate. All patients, and especially those of advanced age and those with multiple comorbidities, should be counseled that their AAA, despite having undergone endovascular treatment, still carries a small but lifelong risk of rupture and therefore requires lifelong annual imaging surveillance. Also, patients undergoing EVAR urgently/emergently or for a ruptured AAA appear to be at especially high risk for loss to annual imaging follow-up and warrant increased attention to improve long-term imaging follow-up rates. These findings point to an important opportunity for quality improvement, particularly in an era in which Medicare seeks to expand its armament of quality improvement measures.

AUTHOR CONTRIBUTIONS

Conception and design: AS, LM, AR
Analysis and interpretation: AS, LM, KG, RG, AR
Data collection: AS, KG, AR
Writing the article: AS, LM, JS, WR, FA, RG, AR
Critical revision of the article: AS, LM, KG, JS, WR, FA, RG, AR
Final approval of the article: AS, LM, KG, JS, WR, FA, RG, AR
Statistical analysis: AS, KG, RG, AR
Obtained funding: AS, AR
Overall responsibility: AS

REFERENCES

1. Lederle FA, Wilson SE, Johnson GR, Reinke DB, Littooy FN, Acher CW, et al. Immediate repair compared with surveillance of small abdominal aortic aneurysms. N Engl J Med 2002;346:1437-44.
2. Mortality results for randomised controlled trial of early elective surgery or ultrasonographic surveillance for small abdominal aortic aneurysms. The UK Small Aneurysm Trial Participants. Lancet 1998;352:1649-55.
3. Schwarze ML, Shen Y, Hemmerich J, Dale W. Age-related trends in utilization and outcome of open and endovascular repair for abdominal aortic aneurysm in the United States, 2001-2006. J Vasc Surg 2009;50:722-9.e722.
4. Lederle FA, Freischlag JA, Kyriakides TC, Padberg FT Jr, Matsumura JS, Kohler TR, et al. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. JAMA 2009;302:1535-42.
5. Chaikof EL, Brewster DC, Dalman RL, Makaroun MS, Illig KA, Sicard GA, et al. The care of patients with an abdominal aortic aneurysm: the Society for Vascular Surgery practice guidelines. J Vasc Surg 2009;50:S2-49.
6. Moll FL, Powell JT, Fraedrich G, Verzini F, Haulon S, Waltham M, et al. Management of abdominal aortic aneurysms clinical practice guidelines of the European Society for Vascular Surgery. Eur J Vasc Endovasc Surg 2011;41:S1-58.
7. Schanzer A, Greenberg RK, Hevelone N, Robinson WP, Eslami MH, Goldberg RJ, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. Circulation 2011;123:2848-55.
8. Wyss TR, Brown LC, Powell JT, Greenhalgh RM. Rate and predictability of graft rupture after endovascular and open abdominal aortic aneurysm repair: data from the EVAR Trials. Ann Surg 2010;252:805-12.
9. Holt PJ, Karthikesalingam A, Patterson BO, Ghatwary T, Hinchliffe RJ, Loftus IM, et al. Aortic rupture and sac expansion after endovascular repair of abdominal aortic aneurysm. Br J Surg 2012;99:1657-64.
10. Mehta M, Paty PS, Roddy SP, Taggert JB, Sternbach Y, Kreienberg PB, et al. Treatment options for delayed AAA rupture following endovascular repair. J Vasc Surg 2011;53:14-20.
11. Jones WB, Taylor SM, Kalbaugh CA, Joels CS, Blackhurst DW, Langan EM 3rd, et al. Lost to follow-up: a potential under-appreciated limitation of endovascular aneurysm repair. J Vasc Surg 2007;46:434-40; discussion: 440-1.
12. Kret MR, Azarbal AF, Mitchell EL, Liem TK, Landry GJ, Moneta GL. Compliance with long-term surveillance recommendations following endovascular aneurysm repair or type B aortic dissection. J Vasc Surg 2013;58:25-31.
13. U.S. Census. Available at: http://www.census.gov/did/www/saipe/data/statecounty/data/2010.html. Accessed November 15, 2013.
14. Klabunde CN, Potosky AL, Legler JM, Warren JL. Development of a comorbidity index using physician claims data. J Clin Epidemiol 2000;53:1258-67.
15. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987;40:373-83.
16. Leurs LJ, Laheij RJ, Buth J. What determines and are the consequences of surveillance intensity after endovascular abdominal aortic aneurysm repair? Ann Vasc Surg 2005;19:868-75.

Submitted Mar 17, 2014; accepted Jun 10, 2014.

Additional material for this article may be found online at www.jvascsurg.org.

Supplementary Table I (online only). International Classification of Diseases, Ninth Revision (*ICD-9*) diagnosis codes and ICD-9 procedure codes used to create the study cohort

Inclusion criteria	
ICD-9 diagnosis code	Definition
441.4	AAA without rupture
441.3	AAA with rupture
ICD-9 procedure code	Definition
39.71	EVAR
Exclusion criteria	
ICD-9 diagnosis code	Definition
441.1, 441.2	TAAA with rupture
441.6, 441.7	TAAA without rupture
441.00-441.03	Aortic dissection
ICD-9 procedure code	Definition
38.35, 38.45, 39.73	Thoracic aorta
38.46, 39.24, 39.26	Visceral artery or renal artery

AAA, Abdominal aortic aneurysm; *EVAR,* endovascular aneurysm repair; *TAAA,* thoracoabdominal aortic aneurysm.

Supplementary Table II (online only). Billing codes used to identify claims for an abdominal or pelvic imaging study

Billing code	*Definition*
CT scan abdomen/pelvis	
74150	CT Abdomen w/o contrast
74160	CT Abdomen with contrast
74170	CT Abdomen with & w/o contrast
72192	CT Pelvis w/o contrast
72193	CT Pelvis with contrast
72194	CT Pelvis with & w/o contrast
74177	CT Abdomen & pelvis with contrast
74178	CT Abdomen & pelvis with & w/o contrast
74176	CT Abdomen & pelvis w/o contrast
74174	CT Angiogram abdomen & pelvis
74175	CT Angiogram abdomen
MRI scan abdomen/pelvis	
74181	MRI Abdomen w/o contrast
74183	MRI Abdomen with & w/o contrast
72195	MRI Pelvis w/o contrast
72197	MRI Pelvis with & w/o contrast
74185	MRA Abdomen with & w/o contrast
72198	MRA Pelvis with & w/o contrast
Duplex scan abdomen/pelvis	
93976/93975	Duplex scan of arterial inflow and venous outflow of abdominal, pelvic, scrotal contents and/or retroperitoneal organs
93979/93978	Duplex scan of aorta, inferior vena cava, iliac vasculature, or bypass grafts

CT, Computed tomography; *MRI,* magnetic resonance imaging; *w/o,* without.